BELLCOMM, INC.
1100 Seventeenth Street, N.W. Washington, D.C. 20036

SUBJECT: Apollo Battery Problems
Case 320

DATE: May 17, 1968

FROM: W. O. Campbell

ABSTRACT

Twenty-one battery problems have occurred and have been solved on the Apollo program during the past two and one-half years. The batteries are silver oxide-zinc, the best generic choice. The solutions have involved design and manufacturing process changes for the most part and have been developed by the vendors assisted by MSFC, MSC, and KSC. No state-of-the-art advances have been required, and no recurrences have been reported.

Recent improvements at Eagle-Picher, the vendor for most of the Apollo batteries, include use of an environmentally controlled common assembly room for all Apollo batteries to minimize manufacturing errors on the manual assembly lines. No failures have been reported on batteries assembled in this area. The use of X-rays, suggested for post-manufacturing inspection, is marginal because of inadequate resolution. Hi-pot testing for post-manufacturing detection of incipient shorts will be continued but will be conducted only at the vendor's plant in order to use improved instrumentation.

It is recommended that continued vigilance by the vendor and the centers be exercised for other improvements to minimize manufacturing errors.

(NASA-CR-95522) APOLLO BATTERY PROBLEMS (Bellcomm, Inc.) 14 p

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MEMORANDUM FOR FILE

INTRODUCTION

Silver oxide-zinc batteries are used in Apollo flight hardware and in many other military and space projects. Of all types which are in a state of development compatible with Apollo requirements and schedule, they are the preferred choice primarily because their energy/weight ratio of 40 watt-hours per pound is much higher than that of other alternatives, such as silver-cadmium (15 watt-hours per pound) and nickel-cadmium (8 watt-hours per pound). The programs which have used silver oxide-zinc batteries include Discoverer, Atlas, Gemini, Agena, Mercury, Mariner, Titan III, Asset, and Surveyor.

The principal vendors in the battery field include Eagle-Picher Industries Incorporated (EP), Electric Storage Battery Incorporated (ESB), Yardney Electric Corporation, and Gould National Battery Incorporated.

APOLLO BATTERIES

Table I lists the Apollo batteries. The launch vehicle batteries offer an activated life of about 120 hours, and are designed to permit high current drain during the relatively short launch vehicle mission. Recharge is not required. They generally bear the vendor designator "MAP." The spacecraft batteries bearing the designator "MAR" or "SAR" are designed for several cycles of moderate current drain and recharge from fuel cell power over an extended mission period. Their activated life is 30 days or more.

As shown in Table I, Eagle-Picher is the vendor of all Apollo batteries except the pyrotechnic batteries and some back-up batteries for the first two S-II stages. These are supplied by Electric Storage Battery. Both of these companies are regarded as reputable vendors in the industry.

PROBLEMS

In the last two and one-half years, twenty-one instances of battery trouble have been reported, some six of which occurred during the Apollo 4 (SA-501/CSM-017) launch preparations. Failure of a battery to perform its function can arise for four basic reasons:

(i) Requirements Deficiency - a discrepancy between the identified requirements and the actual conditions of the mission.

(ii) Design Deficiency - failure of the design information--through shortcomings in concept, definition, materials, or ease of manufacturing--to define a configuration which will meet the requirements.

(iii) Manufacturing Deficiency - failure to make a product in conformance with the design as a result of a discrepancy of commission or omission in building and inspecting the item.

(iv) Usage Deficiency - failure as a result of incorrect status or procedure in operation of the battery.

Table II lists the Apollo battery problems by stages and the applicable failure categories. As shown in the table, problems have been encountered with batteries in the spacecraft and all vehicle stages except S-IB. With two exceptions (Problems 5 and 17) they have involved Eagle-Picher batteries. None of them resulted from a mission usage which violated the established design requirements. Design deficiencies (nine) and deficiencies in manufacturing and inspection (nine) account for the bulk of the problems. There were also three problems resulting from incorrect procedures in the usage of batteries. Appendix A provides detailed information on each case.

CORRECTIVE ACTIONS

In response to seven of the nine problems categorized as design faults, changes have been made in configuration and materials, and no recurrences have been reported. In the other two cases, the failures occurred in testing at specified extremes of temperature and vibration. These testing requirements were modified (relaxed) to reflect updated flight environment information, and no further failures have been reported.

Since 1965, nine problems have been attributed to deficiencies in manufacturing and inspection. MSFC, MSC, and KSC task forces have worked with Eagle-Picher during this time to identify the causes and to institute corrective actions. The task forces noted that the several sizes and types of Apollo batteries were being made in intermittent production runs on several assembly lines in the vendor's plant, and that there were deficiencies in production process control, personnel training, and inspection. These led to such faults as missing and folded plate separators, wire scraps between plates, and insulation damage of wiring. Corrective actions by the vendor have been prompt in each instance; they include assignment of specific trained personnel to the Apollo project.

In response to the latest recommendations of the task teams, Eagle-Picher has instituted an additonal number of corrective actions. These include the provision of an environmentally controlled assembly room for fabrication since mid-January 1968 of all Apollo batteries; and introduction of some procedures in the manufacturing process to increase the assurance of correct assembly. Changes, such as the use of colored separators, have also been made to enhance post-assembly inspection. No manufacturing and inspection problems have been reported since these latest actions were taken.

The three problems categorized as usage deficiencies represent field preparation or usage of the batteries which resulted from insufficient instructions or from violation of requirements. Information which should prevent recurrence has been disseminated to the users.

POSSIBILITIES FOR FURTHER IMPROVEMENT

With the correction of some initial design and materials deficiencies, most of the remaining Apollo problems have been straightforward manufacturing and inspection problems, and the vendor and task team actions have promptly addressed them as they have occurred. Eagle-Picher is investigating techniques to improve the effectiveness of the post-assembly inspection process. Work is being done on X-ray examination. To date this has not been encouraging because resolution to identify plate and separator defects appears marginal. Hi-pot testing has also been under investigation. Properly used, the test is valuable in post-assembly detection of incipient or high impedance shorts. For this reason the test will be conducted at the vendor's plate once per battery and will be discontinued outside the plant.

It is sometimes possible to avoid assembly defects by making changes in the design or fabrication process which reduce the susceptibility to human error. For example, Eagle-Picher has changed to stiffer plate separators. They are also investigating the use of a one-piece separator in the form of a plastic strip, folded in S-fashion through the plate stack, to eliminate missed and/or folded separators.

Further examination of the detailed designs of Apollo batteries might identify other instances in which design changes could reduce the possibility of assembly errors. For example, an alternative solution to Problem 1 (vent nut dropped into battery cell) might be the elimination of the nut by use of a threaded vent hole. Positive elimination of problem 17 (battery plates pushed into wet epoxy) might be the use of bosses in the case.

SUMMARY AND RECOMMENDATION

Silver oxide-zinc is the best generic choice for Apollo batteries. None of the 21 problems have involved state-of-the-art difficulties. A workable solution, involving design and manufacturing process control techniques for the most part, is in effect for each problem. The solutions have been developed by reputable vendors assisted by expertise at MSFC, MSC, and KSC. No recurrences of problems have been reported.

The latest improvements at the Eagle-Picher plant include use of a common assembly room for all Apollo batteries to minimize manufacturing errors on the manual assembly lines. No failures have been reported on batteries assembled in this area. Other suggestions for post-manufacturing inspection include the use of X-rays; however, this technique is marginal because of insufficient resolution. Use of hi-pot testing to detect incipient shorts resulting from manufacturing defects will be continued, but only at the vendor's plant.

It is recommended that continued vigilance by the vendor and the Centers be exercised for other improvements to minimize manufacturing errors.

ACKNOWLEDGMENTS

More than 50 Apollo personnel contributed to the survey. This opportunity is taken to acknowledge their efforts, expertise, and willingness to supply documentation and hardware. Special recognition goes to the four areas to which most of the inquiries were addressed: MSFC-R-QUAL-AE, MSFC-R-ASTR-EAP, MSC-EE4, and KSC-LV-GDC-28.

The documentation is available at this office

William O. Campbell

2031-WOC-mch W. O. Campbell

Attachments
- Tables I, II
- References
- Appendix A

TABLE 1

APOLLO BATTERIES

STAGE	NOMENCLATURE	USAGE	PART NUMBER[1]	QU. EA.	APPROX. AMP. HRS.
S-1B	1D10	201-12	EP MAP 4182-7	1	33
	1D20	201-12	EP MAP 4182-7	1	33
S-IC	1 (MEASURING)	501-5	EP MAP 4182-5	1	21
	2 (VISUAL INSTR.)	502-3	EP MAP 4182-5	1	21
	3 (VISUAL INSTR.)	502-3	EP MAP 4182-5	1	21
	4 (VISUAL INSTR.)	502-3	EP MAP 4227	1	11
	5 (OP'N'L. INSTR.)	501-5	EP MAP 4227	1	11
		506-12	EP MAP 4227	2	11
S-II	MAIN	501-12	EP MAP 4301	1	35
(NOTE 2)	INSTR.	501-12	EP MAP 4301	1	35
	RECIRCULATION	501-12	EP MAP 4301	2	35
S-IVB	FWD. NO. 1	201-2	EP MAP 4229	1	70
		203-12,504-6	EP MAP 4201-41	1	179
		501-3	EP MAP 4201-25	1	306
	FWD. NO. 2	201-5,7-12	EP MAP 4205	1	2
		206,501-6	EP MAP 4202	1	12
	FWD. NO. 3	203	EP MAP 4229	1	70
	AFT NO. 1	201-2,4-12	EP MAP 4204	1	47
		203	EP MAP 4229	1	70
		501-6	EP MAP 4201-41	1	179
	AFT NO. 2	201-12	EP MAP 4206	1	14
		501-6	EP MAP 4203	1	50
IU	D-10	201-12,501-12	EP MAP 4240	1	350
	D-20	201-5,501-3	EP MAP 4240	1	350
	D-30	201-12,501-12	EP MAP 4240	1	350
	D-40	201-12,501-12	EP MAP 4240	1	350
CSM	DEV.FLT. INSTR.	009	EP MAP 4095	1	120
(NOTE 3)	PYROTECHNIC	BLK. I	ESB 264	4	1
		BLK. II	ESB 264	2	1
	ENTRY, POST-LAND	020	EP SAR 4265	5	40
		BLK. 1 EXC.020;BLK.II	EP SAR 4265	3	40
	AUXILIARY	UNMANNED	EP SAR 4265	3	40
	CAMERA	BLK. I	EP MAR 4090	1	5
	ACQUIS., DOCK	101	EP MAR 4090	2	5
LM	DEV. FLT. INSTR.	LTA2R, LTA10R	EP MAP 4249	2	5
	EXPL. DEVICES	LM-1 & SUBS	ESB 264	2	1
	MAIN (DESCENT)	LM-1 & SUBS	EP MAP 4324	4	400
	MAIN (ASCENT)	LM-1 & SUBS	EP MAP 4323	2	296

[1] EP: EAGLE-PICHER. ESB: ELECTRIC STORAGE BATTERY.

[2] ESB PROVIDES BACK-UP BATTERIES FOR S-II-1, -2.

[3] BEACONS (GFE) AND FLASHLIGHTS USE DRY CELLS.

TABLE II

APOLLO BATTERY PROBLEMS

PROBLEM	DATE	STAGE	REQUIREMENT	DESIGN	MANUFACTURING	USAGE	TOTAL
1. LOOSE VENT NUT	7/67			x			
2. LACK OF GN_2 PURGE	10/67	S-IC			x		3
3. ENTRAPPED MOISTURE	'65				x		
4. MISSING SEPARATOR	11/67				x		
5. FAILURE IN VIBRATION	MID '67	S-II		x			3
6. INSULATION DAMAGE	10/67				x		
7. LEAKY COVER	10/67					x	
8. LOW VOLTAGE	11/67					x	
9. HEATER RUNAWAY	'66			x			
10. THERMOSTAT WRONG LOCATION	'66	S-IVB		x			6
11. TELEMETRY SENSOR SHORTED	'66				x		
12. NOISY HEATER MODULE	'66			x			
13. PRESSURE-CRACKED CASE	'66	IU		x			2
14. SHOCK-CRACKED CASE	1/67			x			
15. FOLDED SEPARATOR	'65				x		
16. LOW RECHARGE CAPABILITY	'65	CSM				x	4
17. CHEMICAL INTERACTION	'66				x		
18. INTERNAL SHORT	'65				x		
19. LOW TEMP.-CRACKED CASE	1/67			x			
20. PLATE TAB FAILURE	3/67	LM			x		3
21 VIBRATION-MOUNTING RAIL	LATE '66			x			
TOTAL			0	9	9	3	21

REFERENCES

1. MSFC Memorandum for Record dated November 15, 1967, signed by Bramlet, "S-II-1 Stage Battery Problem Encountered During AS-501 Launch Preparations: Eagle-Picher-vendor."

2. Letter dated December 6, 1967, Eagle-Picher (Dines) to MSFC (Bramlet), "Saturn Battery Program Review Meeting."

3. MSFC Memorandum for Record dated December 26, 1967, signed by Bramlet , "Visit to Eagle-Picher Company, Joplin, Missouri," November 30, 1967.

4. Letter dated March 24, 1966, McDonnell-Douglas (Prentice) to MSFC (Godfrey), "Battery Heater Circuits."

5. Letter dated August 6, 1965, MSC (Faget) to NASA Headquarters (Phillips), "Eagle-Picher Batteries for Apollo Vehicles, Quality Experience."

APPENDIX A

APOLLO BATTERY PROBLEMS*

The following problems and solutions cover a period starting about two and one-half years ago and extending to the present. Each problem is classified according to category. The categories are: requirement, design, manufacturing, and usage. About half of the problems occurred early in the reference period and are therefore of historical interest. The remainder of the problems occurred in 1967. Number 4, which occurred in November 1967, (SA-501) is the most recent of these and is in the manufacturing category, as are many of the others. It is described at length for this reason.

S-IB

No battery problems have occurred on the S-IB stage. An MSFC task has been initiated to determine whether or not undetected S-IB battery problems exist. The task highlights include application of heat cycles to battery samples to search for cracks and development of a non-cracking coating that could be applied to the battery exterior to prevent leakage if any cracks occur.

S-IC

1. Problem: Vent nut and retainer dropped into battery cell in July 1967, Problem category: design.

   Action taken: Nut retainer replaced with epoxy cement compatible with cell cover, permanently bonding nut to cell cover.

2. Problem: Shipment in October 1967, (three batteries) without gaseous nitrogen (GN_2) purge. Problem category: Manufacturing.

   Action taken: Vendor rebaked batteries and purged with GN_2. No recurrence noted.

3. Problem: Low output voltage in mid-1965 caused by entrapped moisture. Problem category: manufacturing.

   Action taken: Bake, followed by GN_2 purge to eliminate entrapped moisture.

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*Problems are serially numbered to correspond with Table II.

S-II

4. Problem: Internal short during SA-501 launch preparation (November 1967) caused by omission by Eagle-Picher (EP) of a separator.* Problem category: manufacturing. This problem is described in detail because of its recent occurrence and its category. The solution typifies the effective manner in which the vendor and the centers have worked together to solve the Apollo battery problems.

   Pre-Problem Background (Reference 1)

   a. Vendor's sample batteries passed Qualification test in September 1967.

   b. Vendor Quality Control (Q.C.) practices: 100% plate inspection, 100% separator inspection, separators marked, cell inspection before seal, hi-pot at 500 volts, use of X-rays, and 10% random sample for Q.C. tests.

   c. Q.C. practices not used on other batteries: X-ray, second hi-pot test at KSC.

   Action taken: Better manufacturing process control techniques arising from MSFC and KSC recommendations following a Quality Control audit (References 2 and 3):

   a. Constructed an environmentally controlled battery assembly room for all Apollo batteries. The room has been in use since January 1968. Use of it eliminates manufacturing of the various Apollo batteries in separate factory areas and creates better conditions for control of quality. Batteries from this assembly room are now in use at KSC with no failures reported.

   b. Initiated an inspected count of the separators.

   c. Changed separator color identification from black to red and black.

   d. Evaluated a suggestion to use a separator S-wrap technique. With this technique the separator material is wound back and forth between plates. Use of it should reduce the possibility of a missing separator.

   e. Initiated compilation of common production, Q.C., and reliability standards for all types of Apollo batteries.

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*Separator: plastic sheet to prevent contact between plates.

f. Initiated an evaluation of the use of X-rays, a vendor/center joint evaluation. MSFC has reached the conclusion that use of X-rays does not harm the battery. The conclusion is based on work by the Atomic Energy Commission, Oak Ridge, Tennessee, which reports that the energy levels are nowhere near that which would be required to damage the battery. Atomics International (division of NR) has reached a similar conclusion. The primary concern, however, is the effectiveness of the use of X-rays. Many X-rays have been made at KSC. The current opinion is that the battery plates are so close together that identification of a bent plate or a missing separator is doubtful. The vendor and the stage contractor are continuing the evaluation.

g. Initiated an evaluation of the hi-pot test. Hi-pot tests are valuable in post-assembly detection of incipient shorts when properly conducted. The tests are sometimes characterized by a momentary flow of current occurring so quickly that the transient drop in voltage has not been detected previously. A special circuit is being added to the test equipment to register the drop in voltage. To insure proper conduct of the hi-pot test, it will be performed only at the vendor's factory. Hi-pot testing at KSC will be discontinued.

5. Problem: Failure in 1967 of Electric Storage Battery (ESB) batteries to pass qualification vibration test; lead from stack to terminal broken. Failure ratio: one in ten. Problem category: design.

   Action taken: Battery was redesigned by a new vendor, Eagle-Picher. The new design has been flown on SA-501 and SA-502 with no vibration problems.

6. Problem (SA-501, October 1967): Heater control wire insulation damaged during assembly, allowing contact with adjacent terminal. Problem category: manufacturing.

   Action taken: Incorporated better manufacturing process control techniques to eliminate insulation damage.

S-IVB

7. Problem (SA-501, October 1967): Battery cover was improperly installed, causing a pronounced leak around the seal. Problem category: usage.

   Action taken: Changed field procedure to call for additional steps for installing the battery cover properly.

8. Problem (SA-501, November 1967): After battery was activated and installed, a low voltage condition developed. Problem category: usage.

   Action taken: Incorporated in activation procedure a brief "burn-in" period (load applied to battery) after activation, prior to installation, permitting return of voltage to nominal.

9. Problem: About one and one-half years ago, a heat sink problem (Reference 4) occurred with the output transistors of the battery temperature control module, causing thermal run-away and a battery fire. Problem category: design.

   Action taken:

   a. Redesigned control module heat sink.

   b. Added a redundant thermostat switch.

10. Problem: Early in 1966 a thermal problem was traced to a thermostat improperly located for sensing battery temperature (Reference 4). Problem category: design.

    Action taken: Battery redesigned to place thermostat in proper location.

11. Problem: Early in 1966 telemetry sensor shorted to calibration circuit. Problem category: manufacturing.

    Action taken: Manufacturing test procedure revised to call for use of lower test voltage.

12. Problem: Noise (4,000 hz, Reference 4) coming from temperature control module early in 1966. Problem category: design.

    Action taken: Redesigned control module to eliminate noise.

Instrument Unit

13. Problem: Battery fire during 500 Flight Systems Test in 1966, due to failure of relief valve, creating overpressurization after filling, causing battery cell to crack. Electrolyte ran out, creating short from battery to magnesium case, causing fire. Problem category: design.

Action taken:

a. Changed cell material for better pressurization strength.

b. Used potting compound for better fit between battery cells and case permitting higher cell pressure.

c. Lowered "cracking" pressure of pressure relief valve.

d. Changed assembly method on the valve.

e. Incorporated more rigid Q.C. inspection of pressure relief valve.

14. Problem: In January 1967, different coefficients of expansion (magnesium case, Lustran cell, potting compound) caused Lustran to crack at low temperature. Problem category: design.

Action taken: Used another cell material with smaller coefficient of expansion.

Command and Service Module

15. Problem: (Reference 5) Series of problems early in 1965 consisting of separators being assembled in a folded-down position, exposed cut edges of grid screens, separators with holes in them, defective plates, loose terminals, leaky cells and deep scratches. Problem category: manufacturing.

Action taken: These defects at vendor attributed to one particular individual. Vendor also used stiffer separator ("Viscane") to help prevent folding down; this measure partly successful. Battery no longer required by program.

16. Problem: Apparent short battery life in mid-1965, typically no greater than a few discharge-recharge cycles (Reference 5). Problem due to user inexperience and mishandling, including use of battery after its guaranteed life had been exceeded. Problem category: usage.

Action taken: Procedures were revised to provide more specific instructions about the life and use of the battery.

17. Problem: (Test battery only; problem never occurred on a flight battery.) The assembly method used in 1966 on ESB battery number 264 to connect cells displaced the cell plates downward into a layer of wet epoxy, setting up conditions for an undesirable chemical reaction. Problem category: manufacturing:

Action taken: Vendor bent the completed connection over to prevent downward displacement of cell plates.

18. Problem: A piece of wire, left between the plates of battery type EP SAR 4265, eventually pierced the separator, causing internal short. Problem occurred in 1965 before completion of qualification test. Problem category: manufacturing.

    Action taken: Initiated tighter control of manufacturing assembly process.

Lunar Module

19. Problem: Cracked case occurred in January, 1967, during qualification thermal shock tests on Descent Stage battery. Problem category: design.

    Action taken: Thermal shock requirement found to be unrealistic at low temperatures and changed from original value of -20°F to new value of +20°F.

20. Problem: Failure in March 1967, during acceptance test, of a Descent Stage battery to meet electrical capacity requirement, due to vibration failure of tab from plate to cell terminal. Problem category: manufacturing.

    Action taken: Difficulty traced to defective forming tool; defective tool replaced.

21. Problem: During qualification vibration test late in 1966, mounting rails at end of a Descent Stage battery case failed. Problem category: design.

    Action taken:

    a. Used different alloy.

    b. Changed mounting rail fabrication method.

    c. Reduced vibration levels based on LTA-3 data.

BELLCOMM, INC.

Subject: Apollo Battery Problems
Case 320

From: W. O. Campbell

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